U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 115.

B. T. GALLOWAY, *Chief of Bureau.*

THE DISINFECTION OF SEWAGE EFFLUENTS FOR THE PROTECTION OF PUBLIC WATER SUPPLIES.

BY

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF PLANT INDUSTRY,
OFFICE OF THE CHIEF,
Washington, D. C., August 1, 1907.

SIR: I have the honor to transmit herewith a paper entitled "The Disinfection of Sewage Effluents for the Protection of Public Water Supplies." This deals with a subject of vital importance to sanitarians interested in the protection and purification of water supplies, and I recommend that it be published as Bulletin No. 115 of the series of this Bureau.

This paper was prepared by Mr. Karl F. Kellerman, Physiologist in charge of Water Purification Investigations, in cooperation with Mr. R. Winthrop Pratt, chief engineer of the Ohio State board of health, and Mr. A. Elliott Kimberly, special assistant engineer of the Ohio State board of health and collaborator of this Bureau. The Department of Agriculture has been fortunate in its cooperation with the Ohio State board of health, and I wish to add a word of personal appreciation of the keen interest and enthusiasm shown by Dr. C. O. Probst, the secretary of the board, and his associates, Mr. Pratt and Mr. Kimberly, in the prosecution of this work.

Respectfully,

B. T. GALLOWAY,
Chief of Bureau.

Hon. JAMES WILSON,
Secretary of Agriculture.

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THE DISINFECTION OF SEWAGE EFFLUENTS FOR THE PROTECTION OF PUBLIC WATER SUPPLIES.

INTRODUCTION.

Of the many points in connection with the disposal of sewage there is, perhaps, none that has recently received more attention than the question of the degree of purification that should be required before a sewage effluent is discharged into a stream or other body of water which serves as a source of water supply. It is unnecessary here to take up in detail the various standards or general recommendations that have been made, especially as it is becoming more widely recognized that for every locality there should be established an individual standard which in the case of certain conditions might require no purification and which under certain other conditions might require the removal of all bacteria likely to cause disease, in addition to the greatest possible chemical improvement of the sewage effluent.

Some investigators [a] consider that the purification of a sewage to the nonputrescible point or point of chemical stability is sufficient, basing their conclusion upon the fact that all polluted waters and perhaps all surface waters should be subjected to filtration for the purpose of removing disease germs. The logical conclusion of this point of view has been stated in these very emphatic words, "If the people below select to drink the sewage of the people above, surely they should be held responsible for the cost of manipulating it to their fancy." [b] It would seem, however, that while the plan suggested,[c] to divide the cost of elaborate sewage treatment between

[a] Winslow and Phelps. Investigations on the Purification of Boston Sewage. U. S. Geol. Survey, Water-Supply and Irrigation Paper 185, 1906.

[b] Reid, George. To what Extent must Authorities Purify Sewage? Surveyor and Municipal and County Engineer, vol. 31, No. 788, pp. 274–275; discussion, pp. 275–278. London, February 22, 1907.

[c] Digby, W. Pollard, and Shenton, Henry C. H. Prevention of the Bacterial Contamination of Streams and Oyster Beds. London, published by the Society of Engineers, 1906. [The same, very slightly abridged] Surveyor and Municipal and County Engineer, vol. 30, No. 777, pp. 653–655, December 7; No. 778, pp. 685–688, December 14; discussion, pp. 688–690. London, 1906.

the sewage disposal plant and the water filtration plant affected by the sewage disposal, might be productive only of legal complications, there is a broader interpretation of the principles of public health which not only makes such expenditures a moral obligation on the part of the sewage disposal authorities, but because of these expenditures may show a marked financial gain for the entire community. There can be no doubt that the responsibility of furnishing pure water should fall exclusively upon the company or municipality controlling the water supply, but the degree to which the adjacent sewage disposal plants should aid in protecting a source of supply from pollution should be determined by some unprejudiced central authority. It should be possible also for this same central authority to have jurisdiction over the operation of sewage disposal plants and water purification plants.

It is indisputable that there is much pollution of streams not caused by sewage effluents[a] and that water purification, rather than sewage purification, is in general the essential point in protecting water consumers.[b] Where sewage is rendering a water supply exceedingly dangerous, however, either the water must be disinfected[c] before being distributed to the consumers or, according to what is the more logical first step in economic and æsthetic purification of the water, the polluting sewage must be purified and at least partially disinfected before it is discharged into the stream or lake in question. Filtration of the water supply would almost certainly be required in either case.

Chemical treatment for the sterilization of sewage has often been suggested. A review of the literature, however, shows that in general early attempts were based upon the treatment of crude sewage, the sterilization of which is of course usually more of a disadvantage than an advantage. During the last few years the more scientific principle of disinfecting, not sterilizing, a sewage effluent which has been carried to a fair degree of chemical purity has become more popular and has even been suggested as an aid in emergencies where a city's water supply is dangerously polluted.

In the experiments on the disinfection of sewage effluents to be discussed in this bulletin, copper sulphate and chlorin, two of the most promising of the germicides suggested for disinfecting sewage and water, were experimented with at some length and under as varied conditions as possible.

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[a] Leighton, M. O., River Pollution. Proc. American Water Works Assn., 26th Conv., pp. 61–71; discussion, pp. 71–78. 1906.

[b] Baker, M. N. Notes on Sewage Purification and Public Water Supplies. Proc. American Water Works Assn., 26th Conv., pp. 51–56; discussion by W. P. Mason, pp. 57–58. 1906.

[c] Whipple, George C. Disinfection as a Means of Water Purification. Proc. American Water Works Assn., 26th Conv., pp. 266–280. 1906.

Copper sulphate has been used to disinfect crude and settled sewage before filtration;[a] it has also been used to eradicate troublesome algæ from sewage filters,[b] and its use has been suggested for disinfecting sewage effluents,[c] although extensive tests of its applicability to the latter purpose are lacking.

COPPER SULPHATE EXPERIMENTS.

Our own experiments upon the germicidal effect of copper have been planned to include sewage effluents of different qualities, ranging from highly purified effluents from sand filters to the putrescible effluents from septic tanks. Westerville, The Boys' Industrial School, Lancaster, and Marion, Ohio, were selected for substations, and a preliminary experiment upon fresh sewage was conducted at St. Mary's of the Springs, near Columbus, Ohio.

ST. MARY'S OF THE SPRINGS.

St. Mary's of the Springs is a convent school located near the city of Columbus and has a population of about 175 persons. The sewage from this institution at the present time is discharged into two tanks operated in series. These tanks are 10 feet in diameter and about 6 feet in depth to the flow line; the capacity of each is about 3,050 gallons. Recent measurements indicate that the flow of sewage is in the vicinity of 12,000 gallons for a period of 16 hours, there being practically no flow after 10 o'clock p. m. The sewage discharges from the second tank into a small brook through 12 feet of 8-inch tile. Generally speaking, the plant comprises two reservoirs which retain some of the coarser solids; the first tank contains a thin scum and considerable accumulated sludge; the second shows no scum formation; the sewage as discharged is, of course, highly putrescent.

Dating from about Septemper 1, 1905, it has been the daily practice of the health department of the city of Columbus, Ohio, to apply copper sulphate to the sewage at the inlet of the second reservoir. The quantity of copper sulphate added daily is said to be 6 pounds,

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[a] Newcomb, Edwin L. Copper Sulphate as an Adjunct to Sewage Disposal. Jour. New England Water Works Assn., December, 1905.

[b] The Use of Copper Sulphate at Pawtucket, R. I., to Prevent the Clogging of Sewage Filter Beds by Blanket Growth of Microorganisms. (From the November–December Bul. of the Rhode Island State Board of Health), Engineering News, vol. 57, No. 14, pp. 379–380, 2 figs. New York, April 4, 1907. The same, Engineering Record, vol. 55, No. 13, pp. 413–414, illus. New York, March 30, 1907.

[c] Indian Government. Resolutions on the Working of Septic Tanks. Calcutta, January 6, 1906.

Johnson, George A. Report on Sewage Purification at Columbus, Ohio, Made to the Chief Engineer of the Board of Public Service. Columbus, Ohio, 1905, pp. 471–479.

Rideal, Samuel. Sewage and Bacterial Purification of Sewage. 3d ed., London and New York, 1906, p. 174.

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3 of which are introduced at 9 a. m., the remainder at 3 p. m., roughly approximating a concentration of 63 parts to the million. The copper sulphate in a dry state is placed in a perforated enameled pail, which is then lowered into the liquid to a point opposite the discharge pipe from the first reservoir. The copper sulphate remains suspended here, exposed to the somewhat erratic solvent action of the incoming sewage; at times it is found that the entire quantity of chemical used for one day's dose is not completely dissolved in twenty-four hours.

In making an examination of this plant samples of untreated sewage entering the second tank and of treated sewage leaving the second tank were collected at half-hourly intervals for a period of seven hours on two successive days. Tubes were inoculated and plates were poured in the field in order that the bacterial analysis for the determination of total numbers, acid formers, and the identification of the latter with respect to *Bacillus coli*[a] might be more accurate. All tests were carried through in duplicate. In addition to the collection of samples, measurements of the sewage flow were made at half-hourly intervals.

Table I shows the results of these examinations. From an average of 16 samples of effluent collected on the two days the total number of bacteria to the cubic centimeter developing within forty-eight hours at 20° C. was 5,600,000 for the raw and 65,000 for the treated sewage, giving a reduction of approximately 99 per cent. Platings of the treated effluent when incubated at 37° C. for a period of twenty-four hours averaged 250,000 colonies, of which 36,750, or 14.7 per cent, were acid producing, the majority being *Bacillus coli*. Unfortunately no tests were made to learn the bacterial content of the raw sewage at an incubation temperature of 37° C., and it is impossible to determine whether the percentage reduction of bacteria capable of growing at 37° is greater than that of the development at 20° C., though from past experience this seems reasonable.

TABLE I.—*Results of bacterial analyses of sewage effluents, St. Mary's of the Springs, Ohio.*

Date.	Sampling period.	Bacteria to the cubic centimeter.[a] Untreated sewage.	Treated sewage.	Bacteria removed.
1906.				*Per cent.*
September 17	9.30 a. m. to 4.30 p. m.	5,900,000	60,000	98.99
September 18	8.15 a. m. to 3.15 p. m.	5,300,000	70,000	98.89

[a] Averages of half-hourly duplicate analyses. Incubated at 20° C.

The cost of treating the settled sewage of St. Mary's of the Springs is practically the cost of chemicals and the cost of maintenance, as

[a] Carried through *B. coli* identification recommended by the American Public Health Association.

the construction costs for the plant are practically negligible. With copper sulphate at 6 cents a pound and a daily sewage flow of 12,000 gallons the expenditure for chemicals is 3 cents for each 1,000 gallons, using 6 pounds of copper sulphate a day. The labor cost may be considered to be 25 cents a day. Similar plants applying copper sulphate in the proportion of 63 parts to the million to a sewage flow of 12,000 gallons would require about 6 pounds of copper sulphate daily, costing 36 cents a day. On an annual basis, including labor for one hour a day at 25 cents an hour, the chemical and maintenance cost would be about $222.65, proportioned as follows:

2,190 pounds of copper sulphate, at 6 cents a pound	$131.40
Labor, 365 hours, at 25 cents an hour	91.25
Total	222.65

Capitalized at 5 per cent, this would represent an investment of $4,500.

For crude sewage much better results could probably be obtained by using 100 parts of copper sulphate to each million parts of sewage. For treating 12,000 gallons of sewage at this rate the expense would be 60 cents a day, or $310.25 annually, and the corresponding capitalization would be $6,200.

WESTERVILLE.

The sewage plant at Westerville,[a] Ohio, comprises two small septic tanks which discharge, through an aerating device, on to six primary cinder contact filters, which in turn discharge upon two secondary filters. The plant at the present time is operated continuously, instead of upon the contact principle. The effluent from the primary filters is usually nonputrescible, but at times tends to become unstable and contains considerable crude organic matter. As the effluent from the primary filters was the more accessible, by suitable piping it was conducted through an orifice box where the proper quantity could be diverted for the experiments with copper treatment, the excess being discharged over a waste weir. During this test the flow of sewage was such that the additional head due to the discharge over the waste weir was probably not sufficient to influence measurably the computed discharge of 41,000 gallons in twenty-four hours.

The copper crystals were dissolved in barrels connected in series. The solution in the barrels was conducted to an orifice box, where by means of a ball cock a constant head was maintained upon an adjustable orifice. The quantity of copper sulphate used in each test was based upon the computed flow of 41,000 gallons of effluent in twenty-four hours. The water which was used for dissolving the

[a] For description, see Annual Report Ohio State Board of Health, 1903, p. 560.

copper salt had such a high alkalinity that it was necessary to almost neutralize the carbonates with sulphuric acid before preparing the copper-sulphate solutions, as otherwise the copper would be completely precipitated in the solution tanks. After passing through the orifice box the copper solution was discharged into a small storage reservoir at the same point where the discharge from the sewage effluent orifice box was admitted; the rate of discharge was 0.5 gallon a minute. The concentration of the applied copper solution, of course, varied with the different concentrations studied. At the point of entrance of the sewage effluent and the copper solution there was placed a small longitudinal baffle, serving to effect a thorough mixture of the chemical and the effluent. The storage period, or time of contact of sewage and copper sulphate, was slightly over one hour.

At hourly intervals during the test bacterial samples of the sewage effluent were collected before and after treatment. Samples for chemical analyses were collected at hourly intervals, and the composite sample so obtained was subjected to chemical analysis. In addition, determinations were made in the field for free carbonic acid and for alkalinity before and after treatment.

The initial run was made at a concentration of 5 parts to the million, followed by gradually increased amounts of the chemical until a concentration of 67 parts to the million was reached. It was the general practice to apply copper sulphate at a given concentration for two consecutive days. As will be seen from Table II, the percentage of removal of bacteria grown at 20° C. varied from 95 per cent to 59 per cent, depending upon the concentration of copper sulphate applied and also upon changes in temperature.[a] The removal of bacteria developing at 37° C. was much more erratic than was the case at 20° C., the percentage of removal varying between 28 and 96 for total numbers and between 66 and 100 for acid-producing bacteria. The different concentrations of copper sulphate that were used showed less variation in efficiency than might have been expected.

[a] Moore, G. T., and Kellerman, K. F., Bul. 76, Bureau of Plant Industry, p. 12, 1905. Johnson, George A., Report on Sewage Purification at Columbus, Ohio, Appendix X, p. 478, 1905.

TABLE II.—*Volume of flow, temperature, organic and suspended matters, and efficiency of copper sulphate applied, Westerville, Ohio.*

Date.	Copper sulphate, parts per million.	Volume of effluent treated.	Temperature.		Parts per million.												Putrescibility.	Bacteria per cubic centimeter.						Bacterial removal.			Per cent positive with test for *B. coli*.	
					Carbonic acid.				Oxygen consumed.	Nitrogen as—				Suspended matter.				20° C.		37° C.					37° C.			
					Free.		Half bound.													Total count.		Red colonies.						
			Air.	Effluent.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.		Organic.	Free ammonia.	Nitrites.	Nitrates.	Total.	Volatile.			Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	20° C.	Total colonies.	Red colonies.	Untreated effluent.	Treated effluent.
1906.		*Galls.*	° *C.*	° *C.*																				*P. ct*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Oct. 2	5	41,000	21.0	18.0	34	23	194	198	14	3.5	7.0	0.068	0.015	44	23	+	3,100,000	205,000	83,000	207,000	10,000	1,100	94	−149	89	13	67
3	5	41,000	18.5	17.5	43	26	220	229	12	1.3	8.0	.18	1.0	35	16	+	9,100,000	2,100,000	205,000	42,000	1,400	100	77	80	93	27	63
5	6.7	41,000	22.5	18.0	40	32	210	209	15	9.7	6.0	.16	1.0	24	6	+	430,000	120,000	20,000	14,500	6,500	325	73	28	95	33	45
6	6.7	41,000	13.0	16.0	40	32	177	178	9	2.5	9.0	.21	1.5	37	27	+	69,000	24,000	18,000	5,500	6,000	1,400	66	70	77	21	67
9	10	41,000	7.5	12.0	28	27	192	191	5	1.3	6.4	.16	1.5	26	19	+	75,000	16,000	66,000	11,000	3,400	1,500	79	84	66	5	22
10	10	41,000	4.0	10.0	26	24	202	210	6	1.1	6.0	—	1.8	16	9	+	46,000	16,500	28,000	8,000	1,800	450	65	72	75	—	18
15	13	41,000	23.5	15.0	36	30	230	236	6	1.1	7.2	.20	1.7	10.4	9.6	+	60,000	25,000	25,000	4,000	2,500	250	59	84	90	—	40
16	13	41,000	23.5	15.5	37	32	238	238	7	1.9	8.0	.17	1.5	10.0	8.8	+	70,000	20,000	48,000	7,000	6,600	900	72	86	87	—	82
19	20	41,000	18.0	16.0	35	33	218	214	15	4.9	4.0	.18	1.7	16.0	8.8	+	145,000	26,000	87,000	12,500	1,600	110	82	86	93	—	6
20	20	41,000	17.5	15.5	32	30	221	216	12	3.3	5.6	.18	1.5	7.6	3.6	+	88,000	13,000	69,000	10,000	1,500	110	85	86	93	—	38
25	29	41,000	8.0	14.0	40	36	202	119	14	4.6	8.8	.08	0.8	34	15	+	60,000	3,900	24,000	6,000	1,200	10	75	75	99	—	33
26	40	41,000	12.0	14.5	40	38	211	201	10	3.9	9.0	.07	0.7	36	32	+	60,000	6,200	50,000	3,000	2,500	15	94	94	99.5	—	66
Nov. 3	40	41,000	14.0	13.0	41	39	176	173	15	1.5	11.0	.07	0.5	17	17	+	370,000	7,000	130,000	6,000	3,000	00	95	96	100	—	—
5	40	41,000	19.5	14.0												+	46,000	13,000	51,000	5,000	11,000	300	91	91	97	—	62
8	67	41,000	19.5	13.0	41	40	218	214	39	5.1	10.0	.03	0.2	30	—	+	175,000	47,000	115,000	16,000	7,700	800	86	87	88	—	41
9	67	41,000	16.0	13.5	39	38	210	206	16	3.9	10.0	.05	0.0	36	—	+	220,000	21,500	47,000	12,000	6,500	600	74	75	91	—	33

On the basis of treating daily 41,000 gallons of effluent from the primary contact filters, the initial cost of a plant for applying the germicidal chemical would be $70 in round numbers. Considering a satisfactory removal of pathogenic organisms to be produced by a concentration of 40 parts to the million, the daily quantity of copper sulphate required would be 13.7 pounds; the cost for chemicals would be about 82 cents and for 2 hours' labor, 50 cents. The annual cost with copper sulphate at 6 cents a pound and labor at 25 cents an hour would then be as follows:

5,000 pounds of copper sulphate at 6 cents a pound	$300.00
Labor, 730 hours at 25 cents an hour	182.50
Total	482.50

Capitalized at 5 per cent, this would represent an investment of $9,650.

BOYS' INDUSTRIAL SCHOOL, LANCASTER.

The Boys' Industrial School[a] is a State institution located near Lancaster, Ohio, and has a population of about 1,100 persons. The sewage from the institution is treated on twenty-three intermittent sand filters which receive the crude sewage which has been subjected only to rough screening as a preliminary treatment. The sewage flow at the institution, from measurements made by the State board of health, averages about 160,000 gallons in twenty-four hours. In carrying out the copper experiments at Lancaster, in distinction from applying a constant quantity of copper sulphate to a constant quantity of effluent, as was the case at Westerville, it was thought most practicable to apply the chemical to the entire effluent flow, carrying out the experiments with a view to learning the quantity of copper sulphate required to destroy coli-like organisms when the sewage effluent was flowing at a maximum rate.

The effluent from the sewage filter discharges into a 20-inch main collecting drain, which also serves in times of storms to carry off storm water from some of the neighboring hills. At the outlet of the effluent drain a weir was constructed having a length of 1 foot and a height of 15 inches. Over this the sewage effluent was caused to flow. Suitable means were provided for observing the elevation of water on the crest of the weir. The effluent drain from the sewage plant discharges into a small brook in which a dam was constructed about 200 feet from the weir. This improvised reservoir gave a storage period of from three to four hours, depending upon the rate of flow from the filters.

The quantity of copper sulphate applied was based upon a sewage flow of 150,000 gallons during the hours the experiments were con-

[a] For description, see Annual Report Ohio State Board of Health, 1903, p. 515.

ducted, and at the beginning of the test was calculated to afford a concentration of 5 parts to the million. The rate of flow of the copper solution was practically constant at 0.75 gallon a minute, but the flow of the sewage effluent varied widely; consequently the resulting concentration of copper sulphate showed the same variations.

Bacterial and chemical samples of the effluent before and after treatment, respectively, were collected at hourly intervals, as at Westerville. They were examined for total numbers and for colonies developing at 37° C. Determinative tests for *Bacillus coli* were carried out by fishing three colonies from one of the duplicate plates of each hour's series for both the untreated and treated effluent. As the concentration of the copper sulphate increased and the bacteria began to decrease this procedure was not rigidly followed, and in the case of small development all of the acid-forming colonies were subcultured. All of the bacterial work was carried out in the field, including the sterilization of plates and the subculture work.

The concentration of copper sulphate applied was increased on each successive run until a maximum of 20 parts to the million was reached, based on a flow of 150,000 gallons. From the fifteen-minute weir readings the average flow of effluent was computed, and from these data the actual average concentration of the copper sulphate on a given day was determined. These results are recorded in detail in Table III.

Careful study of Table III shows that from the public-health standpoint the treatment at Lancaster was more satisfactory than either of the two preceding cases. The percentage of removal of bacteria developing at 20° C. was in one case lower, but the removal of the bacteria developing at 37° C. was much greater and the elimination of acid colonies and *Bacillus coli* was almost complete. The more efficient action of copper sulphate at Lancaster is undoubtedly due to the better chemical condition of the sewage effluent, especially its greater freedom from organic matter[a] and its freedom from carbonates.

[a] Johnson, George A. Report on Sewage Purification at Columbus, Ohio, 1905, p. 474.

TABLE III.—*Volume of flow, temperature, carbonic acid, organic and suspended matters, and efficiency of copper sulphate at different concentrations, Boys' Industrial School, Lancaster, Ohio.*

Date.	Copper sulphate (parts per million).			Volume of effluent.			Temperature.		Parts per million.											Bacteria per cubic centimeter.						Bacterial removal.			Per cent positive with test for *B. coli*.	
									Carbonic acid.					Nitrogen as—				Suspended matter.		20° C.		37° C.					37° C.			
									Free.		Half bound.											Total count.		Red colonies.						
	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Air.	Effluent.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Oxygen consumed.	Organic.	Free ammonia.	Nitrites.	Nitrates.	Total.	Volatile.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	20° C.	Total colonies.	Red colonies.	Untreated effluent.	Treated effluent.
1906.				*Galls.*	*Galls.*	*Galls.*	*° C.*	*° C.*																		*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*
Nov. 16	8.8	6.4	7.8	102,000	80,000	88,000	8.3	10.0	11	8	22	22	16	4.4	5.0	0.30	5.0	74	31	64,000	48,000	6,750	1,300	859	131	25	81	85	50	33
19	7.5	2.4	4.2	363,000	118,000	209,000	8.0	9.3	25	22	10	15	18	5.3	2.5	.30	25.0	64	23	130,000	26,500	14,800	5,400	936	95	80	64	90	33	28
20	8.9	6.0	7.0	220,000	151,000	189,000	21.6	12.5	27	21	16	30	....	....	....	....	....	....	....	78,000	11,000	14,000	700	50	1	86	95	98	60	0
21	14.0	13.0	14.0	138,000	126,000	129,000	23.0	13.5	16	13	18	18	16	4.7	2.3	.50	25.0	60	22	75,000	9,600	15,500	600	75	0	88	97	100	33	0
22	25.0	21.0	22.0	126,000	118,000	122,000	4.4	11.0	6	7	11	15	13	3.6	5.0	.24	25.0	71	31	55,000	6,800	5,700	200	95	0	88	97	100	54	0
27	11.0	7.5	9.1	118,000	80,000	96,000	5.5	9.0	17	10	17	18	31	2.0	5.0	.05	17.0	62	20	225,000	28,000	21,000	1,600	890	5	88	93	99	80	57
Dec. 4	9.4	8.3	8.3	80,000	70,000	80,000	2.5	6.0	11	11	18	17	21	6.5	2.5	.30	5.0	85	52	70,000	3,800	5,300	180	310	8	95	97	98	.....	14

A duplicate test was carried through a few months later, when the temperature was much lower. The effluent was somewhat better organically, however, perhaps offsetting the effect of the lower temperature, and the bacterial removal was only slightly reduced, as is shown in Table IIIa.

TABLE IIIa.—*Volume of flow, temperature, organic and suspended matters, and efficiency of copper sulphate applied to effluent, Boys' Industrial School, Lancaster, Ohio.*

Date.	Copper sulphate, parts per million.			Volume of effluent treated.			Temperature.		Parts per million.												Putrescibility.	Bacteria per cubic centimeter.						Bacterial removal.			Per cent positive with test for *B. coli*.	
										Nitrogen as—				Suspended matter.		Carbonic acid.						20° C.		37° C.					37° C.			
																Free.		Half bound.						Total count.		Red colonies.						
	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Air.	Effluent.	Oxygen consumed.	Organic.	Free ammonia.	Nitrites.	Nitrates.	Total.	Volatile.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Dissolved oxygen.		Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	20° C.	Total colonies.	Acid colonies.	Untreated effluent.	Treated effluent.
1907.				*Galls.*	*Galls.*	*Galls.*	*° C.*	*° C.*																				*P.c.*	*P.c.*	*P. c.*	*P.c*	*P. c.*
Jan. 29	10	7.9	8.5	191,000	150,800	177,000	−0.5	4.0	11	0.7	3.6	0.36	2.0	37	33	14	13	22	22	6.8	0	49,000	5,400	8,800	1,300	250	100	89	85	60	75	25
30	13	12	13	177,800	150,800	158,000	−2.0	4.0	13	1.6	4.0	1.20	2.0	18	18	14	13	21	21	....	0	58,000	5,300	9,000	300	600	1	91	97	99.9	57	25
31	6.6	4.9	5.8	204,300	150,800	171,400	0.0	4.0	14	1.2	4.0	1.20	2.0	14	13	14	13	22	21	....	0	82,000	8,000	12,000	565	260	45	88	95	83	60	.....

The daily application of copper sulphate to the Lancaster sand filter effluent with its flow of 160,000 gallons a day would require 17.3 pounds of copper sulphate, and the cost of this chemical would be about $1.04 a day, based on applying 13 parts of copper sulphate to each million gallons of effluent.

The cost of constructing the Lancaster plant used in these experiments and capable of treating sewage at the rate of 160,000 gallons for six hours was $29. However, a fair estimate of the cost of a plant under practical conditions for continuous treatment would be about $92, proportioned as follows:

2 solution tanks, 1,400 gallons capacity	$45.00
Orifice box	8.75
Brass orifice	2.00
Float control	1.25
Pipe	5.00
Lumber	5.00
Labor	25.00
Total	92.00

The maintenance cost per annum on the above basis would be as follows:

6,325 pounds of copper sulphate, at 6 cents a pound	$379.50
Labor, 365 days, at $2 a day	730.00
Total	1,109.50

Capitalized at 5 per cent, this would represent an investment of $22,000.

MARION.

The sewage disposal plant at Marion, Ohio, has been described in detail,[a] and it is necessary here only to refer to the plant as a combination of septic tanks, contact filters, and sand filters, handling about 600,000 gallons of sewage daily.

To provide a storage reservoir for the copper-sulphate-treated sewage a dam was built in the effluent sewer about 900 feet west of the disposal plant and a cofferdam composed of 6-inch sheathing was constructed at the outlet of the effluent sewer into Rock Swale Creek. The exposed height of the sheathing was such that in all but extreme flood stages the effluent would discharge into the creek in a clear sheet. The object of thus protecting the outlet of the effluent sewer was to overcome possible outside contamination of the copper-treated effluent due to backwater from the creek, which quite probably receives considerable quantities of domestic sewage. During

[a] Pratt, R. Winthrop. Combined Septic Tanks, Contact Beds, Intermittent Filters and Garbage Crematory, Marion, Ohio. Engineering News, vol. 55, No. 8, pp. 197–201, 5 figs. New York, February 22, 1906.

the experiments the waters of the creek rose so as completely to overflow the cofferdam, but on such days no tests were made. In all of the runs it was possible to collect samples of the effluent as discharged without danger of contamination from the waters of the creek. The storage or contact period of sewage effluent and copper sulphate was determined to be about one hour. The copper-sulphate solution, prepared in a solution tank of 1,780 gallons capacity, was discharged at the rate of 2 gallons a minute.

At the present time the disposal plant is hand operated in the daytime only; during the night the contact filters are operated continuously. Beginning at about 7 o'clock a. m. and continuing until about 5 p. m. the normal hand operation of the plant is resumed and it was during such normal operation that the copper experiments were carried out. From 7 o'clock a. m. until 10 a. m. practically no water is discharged into the effluent channel; hence all of the tests began at about 10 a. m. Samples were collected at half-hourly intervals, an allowance being made for the storage period of one hour.

The results of these experiments, shown in detail in Table IV, are somewhat disappointing. The degree of bacterial purification did not equal that obtained at Westerville and, as at Westerville, a great increase in the quantity of copper sulphate applied caused but slightly increased efficiency. The chemical condition of the effluent at Marion was somewhat similar to that at Westerville, but the time of contact with copper sulphate was much shorter. As several investigators[a] have shown, time of contact is a very important element in the germicidal action of copper, and the low bacterial removal is probably due to this factor.

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[a] Gildersleeve. Studies on the Bactericidal Action of Copper on Organisms in Water. American Journal of Medical Science, n. s., vol. 129, No. 5, pp. 754–760. Philadelphia and New York, May, 1905.

Johnson, George A. Report on Sewage Purification at Columbus, Ohio, 1905.

Kraemer, Henry. Copper Treatment of Water. American Journal of Pharmacy, vol. 16, No. 12, pp. 574–579. Philadelphia, December, 1904.

Phelps, E. B. Experiments on the Storage of Typhoid-Infected Water in Copper Canteens. American Public Health Association, Report, vol. 31, part 1, pp. 75–90. 1905.

Moore, G. T., and Kellerman, K. F. Method of Destroying or Preventing the Growth of Algæ and Certain Pathogenic Bacteria in Water Supplies. Bul. 64, Bureau of Plant Industry. 1904. Copper as an Algicide and Disinfectant in Water Supplies. Bul. 76, Bureau of Plant Industry. 1905.

Kellerman, K. F., and Beckwith, T. D. The Effect of Copper upon Water Bacteria. Bul. 100, Pt. VII, Bureau of Plant Industry, pp. 57–71. 1907.

TABLE IV.—*Volume of flow, temperature, organic and suspended matters, and efficiency of copper sulphate applied to effluent, Marion, Ohio.*

Date.	Copper sulphate, parts per million.			Volume of effluent treated.			Temperature.		Parts per million.												Putrescibility.	Bacteria per cubic centimeter.						Bacterial removal.			Per cent positive with test for *B. coli*.	
									Oxygen consumed.	Nitrogen as—				Suspended matter.		Carbonic acid.				Dissolved oxygen.		20° C.		37° C.					37° C.			
																Free.		Half bound.						Total count.		Red colonies.						
	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Air.	Effluent.		Organic.	Free ammonia.	Nitrites.	Nitrates.	Total.	Volatile.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.			Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	20° C.	Total colonies.	Acid colonies.	Untreated effluent.	Treated effluent.
1906.				*Galls.*	*Galls.*	*Galls.*	°*C.*	°*C.*																				*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Dec. 19	5	3	3	732,000	391,000	640,000	3.1	6.0	12	2.3	5.6	0.22	4.4	21	10	21	21	142	140	6.5	0	290,000	67,000	93,000	44,000	1,200	1,300	77	53	− 8	38	63
20	9	4	6	596,000	284,000	469,000	3.0	8.2	9	7.3	4.6	.18	0.0	29	13	17	17	142	142	4.0	0	400,000	78,000	390,000	59,000	3,200	1,200	80	85	62	29	50
27	16	5	7	779,000	249,000	553,000	1.5	5.5	17	9.9	6.0	.15	4.4	22	11	26	24	143	143	4.7	0	410,000	170,000	75,000	36,000	12,000	4,300	58	52	63	.....	44
28	22	7	10	732,000	217,000	553,000	3.6	7.5	14	2.3	5.6	.20	5.0	23	10	36	35	139	139	4.0	0	450,000	125,000	140,000	25,000	16,000	4,800	72	82	70	.....	44
1907.																																
Jan. 2	36	10	13	829,000	217,000	596,000	6.0	8.3	15	2.1	5.0	.50	6.0	21	12	26	26	128	128	6.8	0	380,000	97,000	58,000	19,000	6,000	2,500	74	67	60	.....	78
7	27	12	17	926,000	427,000	686,000	15.0	10.0	10	6.3	0.0	.80	6.0	23	11	25	25	110	110	6.8	0	84,000	33,000	26,000	12,000	4,000	1,800	61	54	55	.....	67
9	37	27	32	985,000	732,000	829,000	4.7	7.7	10	3.1	4.0	.84	3.0	39	16	16	16	114	114	6.4	0	22,000	5,400	38,000	13,000	5,000	1,000	75	67	80	.....	33
10	53	40	48	985,000	779,000	829,000	.8	7.0	10	2.3	4.0	.90	6.0	29	10	17	17	128	128	5.9	0	36,000	7,500	21,000	4,000	5,500	450	78	81	92	.....	53
14	154	110	116	732,000	525,000	689,000	9.8	9.5	10	1.9	3.6	.40	4.0	24	11	•27	26	123	123	6.1	0	84,000	7,000	28,000	2,000	5,000	560	92	93	89	.....	31

The application of copper sulphate to the Marion sand-filter effluent with a daily flow of 600,000 gallons on a basis of applying 20 parts of copper sulphate to each million gallons of effluent would cost $6 a day for chemicals, and the cost of constructing a plant for applying the copper sulphate would be about $151, the main items being as follows:

3 1,500-gallon solution tanks	$99.00
Pipe and lumber	20.00
Orifice box and float control	10.00
Brass orifice	2.00
Labor	20.00
Total	151.00

The cost of treatment annually on the above basis—that is, using copper sulphate to the extent of 20 parts to the million—would be about $2,920, proportioned as follows:

36,500 pounds of copper sulphate, at 6 cents a pound	$2,190.00
Labor, one man, 365 days, at $2 a day	730.00
Total	2,920.00

Capitalized at 5 per cent this would represent an investment of $58,000.

CHLORIN EXPERIMENTS.

After completing the experiments with copper sulphate it was decided to discontinue the copper work and experiment with the use of chlorin in the disinfection of sewage effluents of different degrees of purity. The use of hypochlorites or electrolytic chlorin has been studied for some years and processes based upon the use of chlorin have been installed for sewage treatment at some places. Unfortunately these processes usually were expected to purify as well as disinfect sewage and necessarily were unsuccessful. It is true that in the case of certain hospitals it may be desirable to disinfect the crude sewage discharged from them and this may be done satisfactorily by means of chlorin[a] without interfering with the subsequent biological phenomena of purification.[b] Generally speaking, however, the proper function of germicides in dealing with a large quantity of sewage is that of improving the biological character of the previously chemically purified effluent. This chemical purifica-

[a] Schumacher. Die Desinfektion von Krankenhausgruben mit besonderer Berücksichtigung des Chlorkalkes und ihre Kontrolle. Gesundheits-Ingenieur, 28th year, No. 22, pp. 361–368, August 10; No. 23, pp. 376–384, August 19; No. 24, pp. 393–397 August 30. Munich, 1905.

[b] Dunbar and Korn. Zur Desinfektion von Abwässern mit gleichzeitiger Reinigung derselben. Gesundheits-Ingenieur, 27th year, No. 2, pp. 17–20. Munich, January 20, 1904.

tion may be only partial, as in the case of the effluent from septic tanks,[a] or complete, as in the case of a high-grade sand-filter effluent. This phase of the subject has recently attracted considerable attention, due perhaps to the advocacy of the use of chlorin for preventing the dangerous sewage contamination of shellfish beds.[b]

Our first experiments to determine the efficiency of chlorin as a germicide were made at Lancaster, together with a few laboratory experiments in regard to chlorin absorption by the organic matter in the effluent under treatment and in artificial mixtures containing different amounts of crude organic matter. Similar and more exhaustive experiments were conducted at Marion.

As the most inexpensive and practical source of chlorin for the experiments in question, calcium hypochlorite, or bleaching powder, was selected. This commercial product will cost, upon an average, about 3 cents a pound, and in large quantities may be purchased for 2½ or 2¾ cents a pound. The strength of the commercial chlorid of lime in bulk varies widely and according to analyses of the commercial product purchased in Columbus, Ohio, ranges from 18 to 25 per cent of available chlorin, depending largely upon the degree of exposure to which it has been subjected. As an average cost figure it may be stated that commercial chlorid of lime packed in large air-tight drums and guaranteed to contain 25 per cent of available chlorin may be purchased in Ohio for 2½ cents a pound. On this basis the data of cost have been calculated.[c]

For the sake of convenience and accuracy in our experimental work, it was decided to take advantage of a product placed on the market in 10-pound sealed containers, costing 4 cents a pound and showing on analysis 34 per cent of available chlorin. This product, of course, was more uniform than the cheaper product purchased in bulk and, moreover, was not liable to decreasing chlorin content due to exposure.

According to the experience gained at Lancaster and Marion, the preparation of the hypochlorite solution is an important feature in

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[a] Indian Government. Resolutions on the Working of Septic Tanks. Calcutta, January 6, 1906.

[b] Digby, W. Pollard, and Shenton, Henry C. H. Prevention of the Bacterial Contamination of Streams and Oyster Beds. London, published by the Society of Engineers, 1906.

Phelps, E. B., and Carpenter, W. T. The Sterilization of Sewage Filter Effluents. Technology Quarterly, vol. 19, No. 47, pp. 382–403. Boston, December, 1906.

Phelps, E. B. The Sterilization of Sewage Filter Effluents. Science, vol. 25, No. 647, pp. 808–809. Garrison, N. Y., May 24, 1907.

Kershaw, John B. C. Electrolytic Methods of Sewage Sterilization. Surveyor and Municipal and County Engineer, vol. 30, pp. 662–664, 749–750. London, 1905.

[c] In some localities bleaching powder in sealed containers can be purchased at from 1½ to 2 cents a pound.

the successful chlorin treatment of sewage effluents. It was found that unless special precautions are taken in dissolving the bleaching powder, many large lumps which inclose chlorin remain and materially reduce the efficiency of a given weight of bleaching powder.

The method of preparation found by our experience to give the best results is as follows: A weighed quantity of bleaching powder is placed in a shallow box and covered with sufficient water to form a smooth paste. More water is then added until the heavier particles settle out, thus allowing the soluble and finely divided chlorid of lime to be decanted. After decantation more water is added, the coarse lumps are broken up, and the process repeated until as much as possible has gone into solution. The importance of thoroughly mixing the chlorid of lime solution and of grinding the dried chlorid as finely as possible can not be too strongly emphasized; otherwise a loss of from 10 to 30 per cent may take place, especially in the case of low-grade bleaching powder. Experiments with a high-grade bleaching powder of known strength indicate that the loss of chlorin when the above precautions are taken is not more than 1 per cent.

BOYS' INDUSTRIAL SCHOOL, LANCASTER.

The leading results obtained during the first series of chlorin tests carried out at Lancaster are listed in Table V, from which it appears that none of the samples of treated effluent examined contained acid-forming colonies; the removal of coli-like organisms was therefore practically 100 per cent. On each day six samples were collected and were plated in duplicate upon lactose-azolitmin agar, so that the results represent averages of 36 samples with 1 cubic centimeter examined in each case.

Accompanying the complete removal of coli-like organisms, the treatment with chlorin in amounts as indicated effected a removal of total organisms of 99.8, 99.9, and 99.9 per cent, respectively. In organic compounds the effluent under treatment was substantially similar to that found during the copper experiments, and the temperature of the effluent was practically at the maximum density of 4° C. In reviewing the results it is interesting to note the increase in dissolved oxygen, presumably arising from the liberation of oxygen from the calcium hypochlorite. It should be noted further that in practically all instances by means of the iodo-starch tests residual chlorin was detected at the discharge weir after a storage of about three hours. The hypochlorite solution was tested twice during a six-hour run, but in that time was found to be almost constant. This solution was discharged into the sewage effluent at the rate of 0.75 gallon a minute, and variations in the quantity of chlorin applied were made by changing the strength of the hypochlorite solution.

TABLE V.—*Volume of flow, temperature, organic and suspended matters, and efficiency of calcium hypochlorite applied to effluent, Lancaster, Ohio.*

Date.	Available chlorin. Parts per million.			Volume of effluent treated.			Temperature.	
	Maximum	Minimum.	Average.	Maximum.	Minimum.	Average.	Air.	Effluent.
1907.				*Gallons.*	*Gallons.*	*Gallons.*	*° C.*	*° C.*
Feb. 8	4.0	3.2	3.6	234,800	191,000	208,200	2.0	4.0
13	6.3	4.0	4.3	191,000	117,800	174,600	11.0	4.0
15	4.1	3.7	4.0	102,000	91,200	94,800	.5	5.0

Date.	Parts per million.																	
	Oxygen consumed.		Nitrogen as—								Suspended matter.		Carbonic acid.				Dissolved oxygen.	
			Organic.		Free ammonia.		Nitrites.		Nitrates.				Free.		Half bound.			
	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Total.	Volatile.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.
1907.																		
Feb. 8	15	13	1.9	....	6.0	5.0	1.20	0.70	2.0	3.0	5	0	20	16	22	21	9.8	11.5
13	16	24	1.7	....	11.0	10.0	1.80	0.90	3.0	3.0	5	0	24	15	33	21	9.6	11.6
15	15	15	.....	....	10.0	8.0	1.60	1.40	3.6	3.0	16	0	30	20	30	27	8.8	7.3

Date.	Putrescibility.	Bacteria per cubic centimeter.						Bacterial removal.			Per cent positive with test for *B. coli.*	
		20° C.		37° C.				20° C.	37° C.			
				Total count.		Red colonies.			Total colonies.	Acid colonies.		
		Untreated effluent.	Treated effluent.	Untreated effluent	Treated effluent.	Untreated effluent.	Treated effluent.				Untreated effluent.	Treated effluent.
1907.								*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Feb. 8	0	100,000	150	15,000	48	140	0	99.8	99.7	100	43	....
13	0	105,000	120	11,000	45	1,500	0	99.9	99.6	100	66	....
15	0	192,500	140	15,000	55	870	0	99.9	99.6	100	60	....

The cost of constructing a plant for treating the sand filter effluent of the Boys' Industrial School with chlorin may be taken at $92. Substantially the same plant could be used as in the case of treatment with copper sulphate.

The estimates upon the cost of chemicals are based upon bleaching powder containing 25 per cent of available chlorin and costing 2½ cents a pound. The annual cost, applying 4 parts to the million of available chlorin to a sand filter effluent flow of 160,000 gallons, would be about $924, including labor, proportioned as follows:

7,770 pounds of bleaching powder, at 2½ cents a pound.........	$194.25
Labor, 1 man, 365 days, at $2 a day.........................	730.00
Total...	924.25

Capitalized at 5 per cent, this would represent an investment of $18,500.

MARION.

The procedure adopted in the chlorin disinfection tests was substantially similar to that followed in the experiments with copper sulphate, but the rate of application of the disinfectant solution was increased to 3 gallons a minute. As the effluents from either the septic tanks or the contact filters could be diverted directly into the effluent sewer, experiments were planned with each of the three grades of sewage effluents—from the sand filters, from the contact filters, and from the septic tanks.

The effluent from the sand filters was first experimented with, and the quantity of chlorin applied during the three runs on the sand filter effluent was on the average 3.8, 3.0, and 1.5 parts to the million. An examination of the tabulated chemical data given in Table VI will show interesting indications as to the effect of the applied chlorin on the character of the treated effluent, pointing to a considerable reduction in free carbonic acid and to an increase in the quantity of dissolved oxygen. The change in the nitrates and nitrites in the case of these three runs is apparently too small to warrant discussion. As shown in Table VI, in the first two runs the sterilizing effect of the chlorin was sufficient to remove 98.8 and 99.7 per cent of the total bacteria, 98.5 and 99.1 per cent of bacteria developing on lactose-azolitmin agar at 37° C., and 100 per cent of the acid-forming bacteria, respectively. The conclusion may therefore be drawn that *Bacillus coli* was not present in the treated effluent. On the third test with a chlorin concentration on the average of only 1.5 parts to the million, the bacterial removals were 94.3 for total bacteria at 20° C., 99.2 for bacteria developing on lactose-azolitmin agar at 37° C., and 99.9 per cent for acid-forming bacteria. The average of the platings at 37° C. in the case of the third run contained but one red colony. This, by full determinative tests, was found to be *Bacillus coli*.

TABLE VI.—*Volume of flow, temperature, organic and suspended matter, and efficiency of calcium hypochlorite applied to sand and contact filter effluents and to septic sewage, respectively, Marion, Ohio.*

Date.	Source.	Available chlorin. Parts per million.			Volume of effluent treated.			Air.	Effluent.
		Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.		
1907.					*Gallons.*	*Gallons.*	*Gallons.*	*° C.*	*° C.*
Mar. 21	Sand effluent	4.9	3.3	3.8	779,000	525,000	686,000	19.0	9.2
22	Sand effluent	4.1	2.2	3.0	876,000	469,000	640,000	26.0	11.3
26	Sand effluent	2.8	.96	1.5	829,000	284,000	525,000	25.0	12.0
28	Contact effluent	14.5	1.7	2.9	1,313,000	156,000	779,000	19.0	11.5
29	Contact effluent	20.4	2.6	5.03	1,446,000	186,000	755,000	21.5	11.5
Apr. 3	Contact effluent	31.8	2.0	4.4	1,143,000	77,000	539,000	19.0	10.6
11	Septic effluent	4.3	3.7	4.3	686,000	596,000	596,000	2.5	10.5
12	Septic effluent	6.2	5.8	6.2	640,000	596,000	596,000	3.0	11.0
15	Septic effluent	8.2	7.0	7.6	640,000	553,000	596,000	8.0	5.6

TABLE VI.—*Volume of flow, temperature, organic and suspended matter, and efficiency of calcium hypochlorite applied to sand and contact filter effluents and to septic sewage, respectively, Marion, Ohio*—Continued.

Date.	Source.	Parts per million.																	
		Oxygen consumed.		Nitrogen as—								Suspended matter.		Carbonic acid.				Dissolved oxygen.	
				Organic.		Free ammonia.		Nitrites.		Nitrates.				Free.		Half bound.			
		Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Total.	Volatile.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.
1907.																			
Mar. 21	Sand effluent..	17	16	3.3	....	0.6	0.7	1.70	1.60	12.0	12.0	2	...	28	21	116	115	4.8	5.8
22	Sand effluent..	16	15	3.2	....	0.7	0.8	1.60	1.60	11.0	11.0	2	...	36	26	132	129	5.0	5.5
26	Sand effluent..	17	17	3.9	....	2.0	1.6	0.60	0.80	9.0	8.6	3	...	34	26	163	163	5.9	7.2
28	Contact effluent........	12	12	0.9	....	7.0	7.0	0.56	1.20	10.4	9.6	5	...	19	15	176	163	0.0	0.0
29	Contact effluent........	15	12	1.3	....	6.6	6.6	0.80	0.60	7.0	6.0	4	...	25	24	185	180	3.1	4.0
Apr. 3	Contact effluent........	26	23	3.6	....	6.0	9.0	0.20	0.19	3.0	1.6	8	...	42	39	176	176	1.5	5.4
11	Septic effluent.	40	42	14.2	....	20.0	20.0	0.06	0.00	0.0	0.2	34	28	25	15	....	....	0.3	2.8
12	Septic effluent.	50	48	14.2	....	20.0	22.0	0.30	0.20	0.0	0.0	32	27	39	20	....	....	1.7	3.0
15	Septic effluent.	48	....	14.0	....	35.0	30.0	0.00	0.00	0.0	0.0	36	30	56	41	250	....	0.0	0.0

Date.	Source.	Putrescibility.	Bacteria per cubic centimeter.						Bacterial removal.			*B. coli* per cubic centimeter.	
			20° C.		37° C.					37° C.			
					Total count.		Red colonies.						
			Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	20° C.	Total colonies.	Acid colonies.	Untreated effluent.	Treated effluent.
1907.									*P. ct.*	*P. ct.*	*P. ct.*		
Mar. 21	Sand effluent.	0	49,000	570	9,800	150	1,300	0	98.8	98.5	100	1,000	Not in 1 c.c.
22	Sand effluent.	0	56,000	140	7,000	60	800	0	99.7	99.1	100	2,000	Not in 1 c.c.
26	Sand effluent.	0	70.000	4,000	20,000	160	4,000	1	94.3	99.2	99.9	2,000	Present in 1 c.c.
28	Contact effluent	0	110,000	2,500	....	....	....	......	97.8	....	....	20,000	Not in 0.5 c.c.
29	Contact effluent.	+	65,000	1,600	73,000	370	10,000	0	97.6	99.5	100	15,000	Not in 0.5 c.c.
Apr. 3	Contact effluent.	+	500,000	800	160,000	400	21,000	3	99.8	99.4	99.9	20,000	Not in 1 c.c.
11	Septic effluent.	+	850,000	1,100,000	1,200,000	240,000	55,000	7,400	−130	80.0	87.0	......	....
12	Septic effluent.	+	4,400,000	550,000	850,000	260,000	60,000	15,000	88.0	70.0	75.0	......	....
15	Septic effluent.	+	600,000	400,000	450,000	190,000	100,000	51,000	36.0	59.0	49.0	......	....

In addition to the enumeration of the acid-forming colonies already mentioned, further data were obtained as to the colon content of the treated effluent by means of the dilution method, using

fermentation tubes, supplemented by determinative tests. This method applied to the untreated effluent in the case of the three runs under discussion indicated the range of *Bacillus coli* as 1,000, 2,000, and 2,000 to the cubic centimeter, respectively. In the case of the treated effluent, however, the organisms were not found in 1 cubic centimeter. In the third run, however, with a chlorin concentration of only 1.5 parts to the million, the presence of *Bacillus coli* was detected in 1 cubic centimeter. At fifteen-minute intervals during these tests the presence of residual chlorin was determined at the weir in the effluent sewer and at the outlet into Rock Swale Creek. The results of these tests in the case of the sand-filter effluent were always negative.

The effluent from the contact filters was now diverted directly to the treating chamber. This effluent, of course, contained organic matter of a more putrescible character than did the sand effluent previously studied. The quantity of chlorin applied ranged from a minimum of 1.7 to a maximum of 14.5 on the first run; on the second run from a minimum of 2.6 to a maximum of 20.4; and on the third run a minimum of 2 to a maximum of 31.8 parts to the million. The quantity of sewage discharged varied widely at different times during the day, depending upon the amount of sewage held in the filter. At the end of a discharge the rate is very small, and during such periods, of course, the strength of chlorin applied was greatly increased.

In this connection, the following tabulation of weir readings of one run with the contact-filter effluent will be of interest as illustrating the fluctuation in the quantity of effluent to be treated. In a case of this sort it is necessary to apply chlorin sufficient to disinfect the maximum rate of flow, but where possible storage facilities should be provided to impound the effluent and thus secure a discharge at a regular rate.

TABLE VII.—*Different rates of flow of contact-filter effluent, Marion, Ohio, March 28, 1907, computed on the basis of a twenty-four-hour constant flow.*

Time of measurements.	Gallons to the twenty-four hours.	Time of measurements.	Gallons to the twenty-four hours.	Time of measurements.	Gallons to the twenty-four hours.
10.30 a. m.	1,312,800	12.15 p. m.	525,100	2.00 p. m.	469,000
10.45 a. m.	1,312,800	12.30 p. m.	778,800	2.15 p. m.	1,253,800
11.00 a. m.	316,000	12.45 p. m.	828,900	2.30 p. m.	828,900
11.15 a. m.	1,085,600	1.00 p. m.	926,300	2.45 p. m.	155,500
11.30 a. m.	685,900	1.15 p. m.	778,800	3.00 p. m.	1,085,600
11.45 a. m.	1,444,800	1.30 p. m.	216,500	3.15 p. m.	525,100
12.00 a. m.	926,300	1.45 p. m.	876,200	3.30 p. m.	1,032,500

The effect of the applied chlorin on the chemical character of the contact-filter effluent is similar to that produced in the sand-filter effluents with the exception that the nitrites in the treated effluent

were considerably higher than in the effluent before chlorin treatment. The average quantity of chlorin, 2.9 parts to the million, sufficed to remove 97.8 per cent of the total organisms. The tests for *Bacillus coli* by the dilution method indicated that the contact-filter effluent contained about 20,000 to the cubic centimeter, but after treatment these organisms usually could not be detected in 0.5 cubic centimeter of the effluent.

In the second run, with an average chlorin application of 5 parts to the million, the reduction of total organisms was 97.6 per cent, that of bacteria developing at 37° C. on lactose-azolitmin agar was 99.5 per cent, and the removal of acid-forming bacteria was 100 per cent. Further, *Bacillus coli* usually was not found in 0.5 cubic centimeter of the treated effluent, while in the untreated effluent it was found in numbers averaging 15,000 to the cubic centimeter. The total organisms in the treated effluent were 1,600, and the total development at 37° C. was 370 to the cubic centimeter. No red colonies were found during this run.

On the third run, with an average chlorin application of 4.4 parts to the million, the total removal of bacteria developing at 20° C. was 99.8 per cent, the removal of bacteria developing at 37° C. was 99.4 per cent, and the removal of acid-forming bacteria was 99.9 per cent. The red colonies developing in the case of the untreated effluent contained 21,000 organisms to the cubic centimeter, while in the treated effluent only 3 were found. The tests by the dilution method, however, indicated that *Bacillus coli* usually was not present in 1 cubic centimeter, although found in the untreated effluent approximately 20,000 to the cubic centimeter.

The tests for residual chlorin in the treated effluent at the manhole in the effluent sewer and at the cofferdam were always negative at the latter point, although occasionally positive at the former. The details of these experiments are shown in Table VI.

Following the experiments with the treatment of the contact filter effluent, attention was directed to the application of chlorin to the effluent from the septic tanks. The addition of approximately 5 parts of chlorin to 1,000,000 parts of septic sewage did not suffice to effect a very material removal of either total bacteria or fermenting organisms. The data given in Table VI show a total bacterial removal ranging from 36 to 88 per cent. A higher concentration of chlorin produced only a slight increase in efficiency. At the highest concentration tested, the acid-forming bacteria in the applied sewage were 100,000 to the cubic centimeter and were reduced by the chlorin treatment to 51,000, showing an average reduction of 49 per cent. The indications from the experiments in the chlorin treatment of the septic effluent are that with the quantity of chlorin applied ranging from 4.3 to 7.6 parts to the million the removal of bacteria is by no

means as complete as is desirable. Tests for the presence of residual chlorin in the treated effluent were carried out, but were negative in every instance.

Following the experiments just discussed, in which the quantity of chlorin applied ranged from 4.3 to a maximum of 7.6 parts to the million, an effort was made to learn the efficiency of greatly increased amounts of chlorin. Such information would appear to be of considerable importance in connection with the disinfection of hospital sewages at times of epidemics in cases where sedimentation alone is the only permanently available means of treating the crude sewage. To this end six experiments in the chlorin treatment of septic sewage were made at Marion, the amount of chemical applied ranging from an average of 7.3 to a maximum average of 48.5 parts to the million. The experiments at these higher concentrations were conducted substantially as those already discussed.

By reference to Table VIII it will be noted that about 25 parts to the million of applied available chlorin were sufficient to remove a substantial proportion of coli-like organisms, although a complete removal of *Bacillus coli* was not accomplished. In the case of the fourth experiment at an approximate concentration of 25 parts to the million, with a sewage flow averaging about 650,000 gallons, the total bacteria in the untreated sewage averaged 800,000 and were reduced to 62,000. The number of bacteria to the cubic centimeter developing on lactose-azolitmin agar at 37° C. was 200,000 and was reduced to 35,000. *Bacillus coli* in this test, as shown by the bile broth fermentation tube method,[a] was present in numbers amounting to 15,000 to the cubic centimeter in the untreated sewage and 50 to the cubic centimeter after chlorin treatment, the reduction being 99.3 per cent.

In the subsequent runs in which the concentration of the applied available chlorin was increased to a maximum average of 48.5 parts to the million the removal of *Bacillus coli* was found only slightly greater than in the case of the application of 25 parts to the million of available chlorin, the number of *Bacillus coli* remaining in the treated sewage ranging from 20 to 200 to the cubic centimeter. In this connection it should be noted that the suspended matter in the septic effluent increased considerably, and this probably in large part explains the low removals obtained with the increased quantity of applied chemical. Observations made during the experiments at Marion emphasize the great effect of the periodic discharge of a septic effluent charged heavily with suspended matters. At such times, no doubt, the absorption of the chlorin is very great, and presumably the

[a] Jackson, D. D. "A new solution for the presumptive test for Bacillus coli." Biological Studies by the Pupils of William Thompson Sedgwick, pp. 292–299. Boston, 1906.

organic matters in suspension in the septic effluent destroy a considerable part of the disinfectant added.

The effect of the different concentrations of applied chlorin in the case of the Marion septic sewage is noticeably erratic in this regard. The conclusion seems tenable that these irregularities are, in great part at least, to be attributed to the presence in the septic effluent of large masses of suspended matter. On this account available evidence seems to point to the strong advisability of thoroughly settling a septic tank effluent in the case of contemplated chlorin treatment, except, of course, in those special cases where the flexibility of the design of the septic tanks is such that a well-settled septic effluent is normally obtained at all times.

TABLE VIII.—*Volume of flow, temperature, organic and suspended matter, and efficiency of calcium hypochlorite applied to septic sewage, Marion, Ohio.*

Date.	Available chlorin (parts per million).			Volume of effluent treated.			Temperature.	
	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Air.	Effluent.
1907.				*Gallons.*	*Gallons.*	*Gallons.*	*° C.*	*° C.*
May 3	7.5	7.0	7.3	779,000	732,000	755,000	16.0	10.5
6	19.6	17.03	18.3	779,000	676,000	709,000	11.0	10.5
10	23.6	22.2	22.9	779,000	732,000	732,000	13.5	10.5
13	27.3	22.2	24.8	732,000	596,000	647,000	27.0	11.0
15	34.6	27.2	30.6	779,000	640,000	698,000	15.5	11.5
17	52.1	44.8	48.5	640,000	553,000	600,000	22.0	11.5

Date.	Parts per million.																
	Oxygen consumed.	Nitrogen as—							Suspended matter.		Carbonic acid.				Dissolved oxygen.	
		Organic.	Free ammonia.		Nitrites.		Nitrates.				Free.		Half bound.			
			Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Total.	Volatile.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.
1907.																
May 3	46	8.0	16.0	16.0	0.50	0.50	0.0	0.0	44	34	59	46	181	181	0.0	2.8
6	51	7.6	18.0	20.0	0.00	0.10	0.0	0.0	47	37	51	43	180	176	0.0	3.1
10	36	6.0	14.0	12.0	0.60	0.50	0.0	0.0	30	14	60	44	171	167	1.2	4.8
13	29	4.0	20.0	16.0	0.20	0.20	0.0	0.0	104	86	62	38	184	183	0.0	3.9
15	42	5.6	20.0	20.0	0.00	0.00	0.0	0.0	77	63	53	39	188	186	0.0	2.3
17	43	4.0	20.0	20.0	0.00	0.06	0.0	0.0	79	69	60	35	197	194	0.0	3.4

Date.	Putrescibility.	Bacteria per cubic centimeter.						*B. coli* per cubic centimeter, bile medium.		Bacterial removal.			
		20° C.		37° C.							37° C.		
				Total count.		Red colonies.							
		Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	Untreated effluent.	Treated effluent.	20° C.	Total colonies.	Acid colonies.	*B. coli*, by bile.
1907.										*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
May 3	+	250,000	290,000	1,000,000	470,000	55,000	35,000	....	....	−16	53	36	....
6	+	1,200,000	950,000	850,000	360,000	45,000	28,000	50,000	10,000	20.0	57.6	38	80.0
10	+	1,700,000	2,500	120,000	800	50,000	0	30,000	100	99.8	99.3	100	99.3
13	+	800,000	62,000	200,000	35,000	48,000	....	15,000	50	92.2	82.5	.....	99.3
15	+	750,000	290,000	....	....	....	....	30,000	150	61.3	.....	.....	99.5
17	+	750,000	72,000	....	....	....	....	30,000	35	90.4	.....	.....	99.8

The cost of constructing a plant for treating the several effluents studied at the Marion sewage plant may be taken as $151, exclusive of arrangements for supplying water to dissolve the chlorid of lime. This estimate allows for continuous treatment at a rate of flow of 600,000 gallons in twenty-four hours.

The cost of applying 4 parts to the million of available chlorin to the sand filter effluent is $730 annually. The total annual cost, including labor but excluding the cost of supplying water for preparing the chlorin solution, would be about $1,620 on the basis of an effluent flow of 600,000 gallons daily. Capitalized at 5 per cent, this would represent an investment of $29,000.

The cost of applying 5 parts to the million of available chlorin to the contact filter effluent would be about $2.50 a day, requiring 100 pounds of the chemical. The total annual cost, including labor but excluding the cost of pumping or otherwise supplying the water for dissolving the germicide, would be about $1,640. Capitalized at 5 per cent, this would represent an investment of $34,000.

Assuming 25 parts to the million as a fair average figure for the disinfection of the septic effluent, provided the same is at all times free from abnormal amounts of suspended matters, the total annual cost, including labor, would be about $5,300. Capitalized at 5 per cent, this would represent an investment of about $106,000.

CHLORIN ABSORPTION EXPERIMENTS.

In connection with studies made at Guilford, England, regarding the treatment of sewage effluents with chlorin, Doctor Rideal concluded that there was a fairly definite relation between the chlorin-consuming power of the effluent and the oxygen consumed resulting from a five-minute boiling test.[a] He states that the ratio of chlorin consumed to oxygen consumed is practically constant; that chlorin in excess of the absorption amount is required for sterilization, and that the quantity of chlorin necessary for treatment can be computed by multiplying the oxygen consumed by the factor 1.7.

In view of the importance attached to chlorin absorption by previous investigators and the fact that a fixed relation between the chlorin and the oxygen consumed, respectively, would be of marked value in the practical control of sterilization with chlorin, it was decided to make certain studies to inquire into the chlorin-oxygen relation for conditions at Lancaster, Ohio. Especially was this

[a] Rideal, Samuel. On the Sterilization of Effluents, etc. Journal of the Royal Sanitary Institute, vol. 26, No. 7, pp. 378–406; discussion, pp. 407–416. London, August, 1905. Oxychloride Sewage Purification. Sanitary Record and Journal of Sanitary and Municipal Engineering, vol. 34, pp. 329–332. London, October 6, 1904. Sewage and Bacterial Purification of Sewage. 3d ed., London and New York, 1906, p. 186.

important since a complete removal of *Bacillus coli* was obtained by the use of slightly less than 5 parts of chlorin to the million, and also since there was noted the presence of residual chlorin after a three-hour storage of the treated effluent. Taking into consideration the average oxygen consumed of the treated effluent, the indications were that the relation between the chlorin and the oxygen consumed was somewhat different from that suggested by Rideal.

Experiments at Lancaster bearing upon the supposed ratio between the chlorin and the oxygen consumed consisted in a series of tests in which various dilutions of crude sewage and of sewage-plant effluent were added to standard solutions of chlorin. The chlorin was, of course, added in the cold, and after a five-minute period of contact the residual chlorin was determined by titration with arsenious acid. A contact period of two hours was also studied to obtain information in regard to the effect of time on the absorption of the chlorin. To obtain the relation between the chlorin consumed and the oxygen consumed the latter was determined in the case of all samples by the standard method of boiling for exactly five minutes with an excess of permanganate in acid solution.

A second method of studying chlorin-absorption phenomena was carried out by adding to a known volume of the sewage effluent varying amounts of chlorin, ranging from 2 to 75 parts to the million. After the end of 0.25, 0.50, 0.75, 1.00, 1.50, 2.00, 2.50, 3.00, and 4.00 hours the presence of residual chlorin was determined by means of iodo-starch paper.

Speaking generally, the results of the experiments carried out at Lancaster as to chlorin consumed were somewhat erratic. In view of the high absorption, moreover, it is difficult to account for the presence of residual chlorin after three hours' storage when only 5 parts of chlorin to the million were being added to the sewage effluent, unless it is due to incomplete displacement in the storage reservoir. However this may be, the results at Lancaster indicated that there was no definite relation between the oxygen consumed and the chlorin consumed and that notwithstanding the high chlorin-absorptive capabilities of the sewage effluent the addition of 5 parts of chlorin to the million sufficed to destroy practically 100 per cent of the organisms of the colon group, indicating that oxygen liberated from the decomposing chlorid of lime accomplished disinfection, although the organic character of the effluent was such that it could absorb many times the quantity of chlorin applied. Referring to Tables IX to XI, inclusive, it will be noted that these results strongly indicate that there is no definite relation between the chlorin-consuming power of the effluent and the oxygen consumed as shown by the five-minute boiling test. Comparing Tables IX and X there will be noted the wide range in the quantity of chlorin absorbed by the effluent. The increase after a two and a

four hour contact, respectively, is also worthy of note. Comparing Tables X and XI there is obtained a rough indication of the effect of the concentration of chlorin upon the absorptive power of the effluent. Speaking generally, it may be said that there is an increased absorption as the organic content of the treated liquid increases, and also as the strength of applied chlorin increases.[a]

It appears that under conditions obtaining in these experiments chlorin up to 7.5 parts to the million would be absorbed from the sewage effluent in about 0.75 hour and that chlorin in concentrations of 10 parts and over would be detected in the treated effluent at the end of four hours. Additional experiments showed entirely different results, however; in one instance a chlorin concentration of 75 parts to the million could not be detected at the end of one hour. Data illustrating these points are given in Tables XIV and XV.

In continuing at Marion, Ohio, the study of the absorption of chlorin by organic matter and the possible relation between such absorption and the oxygen absorption shown by the standard oxygen-consumed process, there were carried out forty-eight separate experiments. These experiments dealt with the question of chlorin absorption and used, respectively, sand filter effluent, contact filter effluent, septic sewage, and crude sewage, each being prepared at different dilutions by the addition of tap water.

TABLE IX.—*Relative absorption of chlorin and oxygen by the Lancaster sand filter effluent with various quantities of tap water. Chlorin concentration of 500 parts to the million.*

Per cent of effluent.	Five minutes' contact.			Five minutes' contact.		
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
100	16	114	7.1	9.3	43	4.5
75	12	47	3.9	7.0	50	7.2
50	8	47	5.9	4.7	29	6.2
25	4	47	11.9	3.5	68	19.4
0	0	118	118.0	0.0	3	3.0

TABLE X.—*Relative absorption of chlorin and oxygen by the Lancaster sand filter effluent with various quantities of tap water. Chlorin concentration of 500 parts to the million.*

Per cent of effluent.	Five minutes' contact.			Four hours' contact.		
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
100	7.3	122	17.0	7.3	93	12.8
75	5.7	....	....	5.7	77	13.6
50	3.7	13	3.5	3.7	9	2.4
25	1.9	52	27.5	1.9	55	29.0
0	0.0	14	14.0	0.0	26	14.0

[a] This latter fact is noted by Rideal.

TABLE XI.—*Relative absorption of chlorin and oxygen by the Lancaster sand filter effluent with various quantities of tap water. Chlorin concentration of 100 parts to the million.*

Per cent of effluent.	Five minutes' contact.			Five minutes' contact.		
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Oxygen consumed (parts per million).	Oxygen consumed (parts per million).	Ratio of chlorin to oxygen.
100	5.6	53.0	9.5	5.5	75.0	13.3
75	4.1	38.0	9.3	4.0	52.0	13.0
50	2.7	14.0	5.1	2.6	43.0	16.3
25	1.4	9.2	6.6	1.3	21.0	16.0
0	0.0	8.8	3.8	0.0	3.5	3.5

TABLE XII.—*Chlorin absorbed by crude sewage diluted with different quantities of tap water. Chlorin concentration of 500 parts to the million.*

Per cent of sewage.	Five minutes' contact.			Four hours' contact.		
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
100	166	266	1.60	166	390	2.34
75	123	202	1.64	123	354	2.69
50	83	174	2.09	83	238	2.87
25	42	68	1.62	42	102	2.42
0	0	118	118.00	0	118	118.00

TABLE XIII.—*Chlorin absorbed by crude sewage diluted with different quantities of tap water. Chlorin concentration of 500 parts to the million.*

Per cent of sewage.	Five minutes' contact.			Four hours' contact.		
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
100	46.0	245	5.3	46.0	327	7.1
75	24.0	32	1.3	24.0	132	5.5
50	13.0	122	9.4	13.0	167	12.8
25	6.5	72	9.0	6.5	114	17.5
0	0.0	14	14.0	0.0	26	26.0

TABLE XIV.—*Chlorin absorption when constant volumes of effluent are treated with different quantities of chlorin for different periods of contact. Volume of effluent treated, 500 cubic centimeters.*

Residual chlorin present indicated by +; absent, by 0.

Applied chlorin (parts per million).	Elapsed time (hours).								
	0.25.	0.50.	0.75.	1.00.	1.50.	2.00.	2.50.	3.00.	4.00.
2.0	0	0	0	0	0	0	0	0	0
4.0	0	0	0	0	0	0	0	0	0
5.0	+	0	0	0	0	0	0	0	0
7.5	+	+	0	0	0	0	0	0	0
10.0	+	+	+	+	+	+	+	+	+
20.0	+	+	+	+	+	+	+	+	+
50.0	+	+	+	+	+	+	+	+	+
75.0	+	+	+	+	+	0	+	0	0

TABLE XV.—*Chlorin absorption when constant volumes of effluent are treated with different quantities of chlorin for different periods of contact. Volume of effluent treated, 500 cubic centimeters.*

Residual chlorin present indicated by +; absent, by 0.

Applied chlorin (parts per million).	Elapsed time (hours).								
	0.25.	0.50.	0.75.	1.00.	1.50.	2.00.	2.50.	3.00.	4.00.
2.0	0	0	0	0	0	0	0	0	0
4.0	0	0	0	0	0	0	0	0	0
5.0	+	+	0	0	0	0	0	0	0
7.5	+	+	+	+	+	+	+	+	+
10.0	+	+	+	+	+	+	+	+	+
20.0	+	+	+	+	+	+	+	+	+
50.0	+	+	+	+	+	+	+	+	+
75.0	+	+	+	0	0	0	0	0	0

Generally speaking, the results of the somewhat exhaustive study of these chlorin-absorption phenomena were very much more consistent than the few data obtained at Lancaster. The work was carried out in a very systematic manner, better facilities were at hand for rapid operation, and consequently the results are to be considered much more reliable.

In tabulating the data they are presented in two different ways, the first intended to show the effect of the concentration of the applied chlorin upon the amount of absorption and the chlorin-oxygen consumed ratio and also the effect of the period of contact upon these same data. To this end, therefore, the four kinds of sewagic liquid studied are listed in Tables XVI to XXXV, inclusive, showing the average results for the different dilutions with tap water, the effect of the time factor and the strength of the applied chlorin upon the chlorin absorption and of the chlorin consumed to oxygen consumed ratio.

In Tables XXXVI to XLII, inclusive, are given the average results of the forty-eight experiments arranged with a view to indicate the effect of organic matter at different concentrations of applied chlorin, the tables being arranged as before with respect to the degree of dilution of the sewage under study.

From the summarized results of the chlorin-absorption studies tabulated the following conclusions may be drawn:

(1) The ratio of chlorin consumed to oxygen consumed in a five-minute period of contact bears no constant relation to the oxygen consumed by the five-minute boiling method.

(2) The concentration of applied chlorin affects the quantity of chlorin absorbed, the absorption at a concentration of 100 parts to the million being fully double that at 50 parts to the million.

(3) Increasing concentrations of chlorin up to 250 parts to the million increase the quantity of absorbed chlorin very materially, but

above this there appears to be very little increased absorption even with a chlorin concentration of 500 parts to the million.

(4) Increasing the period of contact to two hours effects but little increase in the ratio of chlorin consumed to oxygen consumed, except for the higher chlorin concentrations of from 250 to 500 parts to the million.

(5) The actual amount of chlorin absorbed in five minutes by the several liquids tested, under concentrations of chlorin of 50, 100, 250, and 500 parts to the million, ranged as follows:

Crude sewage	24 to 148
Septic sewage	41 to 160
Contact filter effluent	42 to 80
Sand filter effluent	33 to 68

(6) The absorption of chlorin apparently is largely dependent upon the organic content of the liquid treated, increasing materially as the oxygen consumed of the effluent increases, but not in a definite ratio.

(7) For the same concentration of applied chlorin the ratio between the chlorin consumed and the oxygen consumed appears to increase as the organic matters decrease.

(8) The readily oxidizable matter in the septic sewage studied apparently causes a rapid absorption of chlorin, increasing the chlorin-oxygen ratio, especially in the case of the lower concentrations of applied chlorin.

TABLE XVI.—*Relative absorption of chlorin and oxygen by crude sewage.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
50	94	34	0.36	36	0.38
100	94	60	0.64	63	0.67
250	94	144	1.50	178	1.90
500	94	148	1.60	209	2.20

TABLE XVII.—*Relative absorption of chlorin and oxygen by septic effluent.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
50	49	41	0.0	42	0.9
100	49	66	1.3	73	1.5
250	49	163	3.3	179	3.7
500	49	160	2.6	204	3.3

TABLE XVIII.—*Relative absorption of chlorin and oxygen by contact effluent.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
49	24	42	1.7	42	1.7
98	24	81	3.3	85	3.5
244	24	84	3.5	98	4.1
488	24	80	3.3	95	4.0

TABLE XIX.—*Relative absorption of chlorin and oxygen by sand-filter effluent.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
50	19	33	1.6	40	2.1
100	19	54	2.8	60	3.2
250	19	67	3.5	71	3.7
500	19	68	3.6	80	4.2

TABLE XX.—*Relative absorption of chlorin and oxygen by 75 parts of crude sewage diluted with 25 parts of tap water.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
50	70	33	0.47	35	0.5
100	70	72	1.0	.71	1.0
250	70	119	1.7	150	2.1
500	70	107	1.5	166	2.4

TABLE XXI.—*Relative absorption of chlorin and oxygen by 75 parts of septic effluent diluted with 25 parts of tap water.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
50	37	36	1.0	40	1.1
100	37	85	2.3	86	2.3
250	37	125	3.4	141	3.8
500	37	123	3.3	173	4.7

TABLE XXII.—*Relative absorption of chlorin and oxygen by 75 parts of contact effluent diluted with 25 parts of tap water.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
49	21	39	1.9	40	1.9
98	21	63	3.0	71	3.4
244	21	65	3.1	78	3.7
488	21	60	2.9	74	3.5

TABLE XXIII.—*Relative absorption of chlorin and oxygen by 75 parts of sand-filter effluent diluted with 25 parts of tap water.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
49	14	28	2.0	33	2.3
97	14	51	3.6	56	4.0
244	14	51	3.6	54	3.9
486	14	53	3.8	63	4.5

TABLE XXIV.—*Relative absorption of chlorin and oxygen by 50 parts of crude sewage diluted with 50 parts of tap water.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
50	47	29	0.6	30	0.64
100	47	71	1.5	78	1.7
250	47	80	1.7	118	2.5
500	47	83	1.9	112	2.4

TABLE XXV.—*Relative absorption of chlorin and oxygen by 50 parts of septic effluent diluted with 50 parts of tap water.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
50	25	35	1.4	39	1.6
100	25	82	3.3	91	3.6
250	25	82	3.3	128	5.1
500	25	81	3.2	117	4.7

TABLE XXVI.—*Relative absorption of chlorin and oxygen by 50 parts of contact effluent diluted with 50 parts of tap water.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
49	14	35	2.5	36	2.6
98	14	46	3.3	53	3.8
244	14	50	3.6	59	4.2
488	14	37	2.6	53	3.8

TABLE XXVII.—*Relative absorption of chlorin and oxygen by 75 parts of sand filter effluent diluted with 25 parts of tap water.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
49	14	28	2.0	33	2.3
97	14	51	3.6	56	4.0
244	14	51	3.6	54	3.9
486	14	53	3.8	63	4.5

TABLE XXVIII.—*Relative absorption of chlorin and oxygen by 50 parts of crude sewage diluted with 50 parts of tap water.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
50	23	36	1.6	40	1.7
100	23	43	1.9	55	2.4
250	23	43	1.9	70	3.0
500	23	28	1.2	59	2.6

TABLE XXIX.—*Relative absorption of chlorin and oxygen by 50 parts of septic effluent diluted with 50 parts of tap water.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
50	25	35	1.4	39	1.6
100	25	82	3.3	91	3.6
250	25	82	3.3	128	5.1
500	25	81	3.2	117	4.7

TABLE XXX.—*Relative absorption of chlorin and oxygen by 50 parts of contact effluent diluted with 50 parts of tap water.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
49	14	35	2.5	36	2.6
98	14	46	3.3	53	3.8
244	14	50	3.6	59	4.2
488	14	37	2.6	53	3.8

TABLE XXXI.—*Relative absorption of chlorin and oxygen by 50 parts of sand filter effluent diluted with 50 parts of tap water.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
49	9	29	3.2	34	3.8
97	9	36	4.0	44	4.9
244	9	36	4.0	44	4.9
486	9	43	4.8	49	5.3

TABLE XXXII.—*Relative absorption of chlorin and oxygen by 25 parts of crude sewage diluted with 75 parts of tap water.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
50	23	36	1.6	40	1.7
100	23	43	1.9	55	2.4
250	23	43	1.9	70	3.0
500	23	28	1.2	59	2.6

TABLE XXXIII.—*Relative absorption of chlorin and oxygen by 25 parts of septic effluent diluted with 75 parts of tap water.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
50	12	41	3.4	48	4.0
100	12	56	4.7	57	4.8
250	12	47	3.9	62	5.2
500	12	48	4.0	72	6.0

TABLE XXXIV.—*Relative absorption of chlorin and oxygen by 25 parts of contact effluent diluted with 75 parts of tap water.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
49	7	25	3.6	28	4.0
98	7	26	3.7	30	4.3
244	7	27	3.9	36	5.1
488	7	18	2.6	31	4.4

TABLE XXXV.—*Relative absorption of chlorin and oxygen by 25 parts of sand filter effluent diluted with 75 parts of tap water.*

Concentration of chlorin (parts per million).	Five minutes' contact.			Two hours' contact.	
	Oxygen consumed (parts per million).	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.	Chlorin consumed (parts per million).	Ratio of chlorin to oxygen.
49	5	21	4.2	26	5.2
97	5	24	4.8	27	5.4
244	5	27	5.4	24	4.8
486	5	24	4.8	41	8.2

TABLE XXXVI.—*Relative absorption of chlorin and oxygen, showing especially the effect of organic matter; 100 parts of sewage or effluent; contact period, five minutes.*

Concentration of chlorin (parts per million).	Oxygen consumed (parts per million).				Chlorin consumed (parts per million).				Ratio of chlorin to oxygen.			
	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.
50	94	49	24	14	34	41	42	......	0.4	0.9	1.7	......
100	94	49	24	14	60	66	80	......	0.6	1.3	3.3	......
250	94	49	24	14	144	160	84	......	1.5	3.3	3.5	......
500	94	49	24	14	148	160	80	......	1.6	3.6	3.3	......

TABLE XXXVII.—*Relative absorption of chlorin and oxygen, showing especially the effect of organic matter; 75 parts of sewage or effluent diluted with 25 parts of tap water; contact period, five minutes.*

Concentration of chlorin (parts per million).	Oxygen consumed (parts per million).				Chlorin consumed (parts per million).				Ratio of chlorin to oxygen.			
	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.
50	70	37	21	......	33	36	39	28	0.47	1.0	1.9	2.0
100	70	37	21	......	72	85	63	51	1.0	2.3	3.0	3.6
250	70	37	21	......	119	125	65	51	1.7	3.4	3.1	3.6
500	70	37	21	......	107	123	60	53	1.5	3.3	2.9	3.8

TABLE XXXVIII.—*Relative absorption of chlorin and oxygen, showing especially the effect of organic matter; 50 parts of sewage or effluent diluted with 50 parts of tap water; contact period, five minutes.*

Concentration of chlorin (parts per million).	Oxygen consumed (parts per million).				Chlorin consumed (parts per million).				Ratio of chlorin to oxygen.			
	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.
50	47	25	14	9	29	35	35	29	0.6	1.4	2.5	3.2
100	47	25	14	9	71	82	46	36	1.5	3.3	3.3	4.0
250	47	25	14	9	80	82	50	36	1.7	3.3	3.6	4.0
500	47	25	14	9	83	81	37	43	1.8	3.2	2.6	4.8

TABLE XXXIX.—*Relative absorption of chlorin and oxygen, showing especially the effect of organic matter; 25 parts of sewage or effluent diluted with 75 parts of tap water; contact period, five minutes.*

Concentration of chlorin (parts per million).	Oxygen consumed (parts per million).				Chlorin consumed (parts per million).				Ratio of chlorin to oxygen.			
	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.
50	23	12	7	5	36	41	25	21	1.6	3.4	3.6	4.2
100	23	12	7	5	43	56	26	24	1.9	4.7	3.7	4.8
250	23	12	7	5	43	47	27	27	1.9	3.9	3.9	5.4
500	23	12	7	5	28	48	18	24	1.2	4.0	2.6	4.8

TABLE XL.—*Relative absorption of chlorin and oxygen, showing especially the effect of organic matter; 100 parts of sewage or effluent; contact period, two hours.*

Concentration of chlorin (parts per million).	Oxygen consumd (parts per million).				Chlorin consumed (parts per million).				Ratio of chlorin to oxygen.			
	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.
50	94	49	24	19	36	42	42	40	0.38	0.9	1.7	2.1
100	94	49	24	19	63	73	85	60	0.67	1.5	3.5	3.2
250	94	49	24	19	178	179	98	71	1.9	3.7	4.1	3.7
500	94	49	24	19	209	204	95	80	2.2	3.3	4.0	4.2

TABLE XLI.—*Relative absorption of chlorin and oxygen, showing especially the effect of organic matter; 75 parts of sewage or effluent diluted with 25 parts of tap water; contact period, two hours.*

Concentration of chlorin (parts per million).	Oxygen consumed (parts per million).				Chlorin consumed (parts per million).				Ratio of chlorin to oxygen.			
	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.
50	70	37	21	14	35	40	40	33	0.5	1.1	1.9	2.3
100	70	37	21	14	71	86	71	56	1.0	2.3	3.4	4.0
250	70	37	21	14	150	141	78	54	2.1	3.8	3.7	3.9
500	70	37	21	14	166	173	74	63	2.4	4.7	3.5	4.5

TABLE XLII.—*Relative absorption of chlorin and oxygen, showing especially the effect of organic matter; 50 parts of sewage or effluent diluted with 50 parts of tap water; contact period, two hours.*

Concentration of chlorin (parts per million).	Oxygen consumed (parts per million).				Chlorin consumed (parts per million).				Ratio of chlorin to oxygen.			
	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.	Crude sewage.	Septic sewage.	Contact filter effluent.	Sand filter effluent.
50	47	25	14	9	30	39	36	34	0.64	1.6	2.6	3.8
100	47	25	14	9	78	91	53	44	1.7	3.6	3.8	4.9
250	47	25	14	9	118	128	59	44	2.5	5.1	4.2	4.9
500	47	25	14	9	112	117	53	49	2.4	4.7	3.8	5.3

SUMMARY AND CONCLUSIONS.

(1) It is desirable in many instances to remove from the sewage effluent bacteria which might be considered members of the pathogenic group. This is especially necessary when sewage is discharged in the vicinity of shellfish beds or when towns and cities are so intimately related that the standard methods of water purification can not sufficiently protect one community from the sewage of another.

(2) Both calcium hypochlorite and copper sulphate have high germicidal values when acting upon partially purified sewage. Calcium hypochlorite is much more rapid in its action, is more nearly able to bring about complete disinfection at a lower cost, and is less influenced by temperature and by the presence of carbonates. It is liable to deterioration upon standing and is more disagreeable and less convenient to handle than copper sulphate.

(3) The quantity of chlorin immediately absorbed can not be estimated from the determination of the oxygen-consumed factor of the sewage effluent.

(4) The cost per annum for each thousand gallons of sewage treated under the varying conditions experimented with is estimated as follows:

St. Mary's of the Springs, Ohio (average daily flow 12,000 gallons), crude sewage, copper sulphate, $18.55.

Westerville, Ohio (average daily flow 41,000 gallons), effluent from contact filter, copper sulphate, $11.77.

Boys' Industrial School, Lancaster, Ohio (average daily flow 160,000 gallons), sand filter effluent, copper sulphate, $6.93; chlorin, $5.78.

Marion, Ohio (average daily flow 600,000 gallons), sand filter effluent, copper sulphate, $4.86; chlorin, $2.43; contact filter effluent, chlorin, $2.73; septic tank effluent, chlorin, $8.83. In case the

effluent from the septic tank contains much suspended matter a heavier application of chlorin is necessary.

These figures probably approximate the cost for treatment in any city whose sewage is not markedly influenced by industrial wastes. In the small plants here discussed depreciation has not been included in the cost data; it is, of course, a factor which must not be overlooked for operating costs on a larger scale.

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